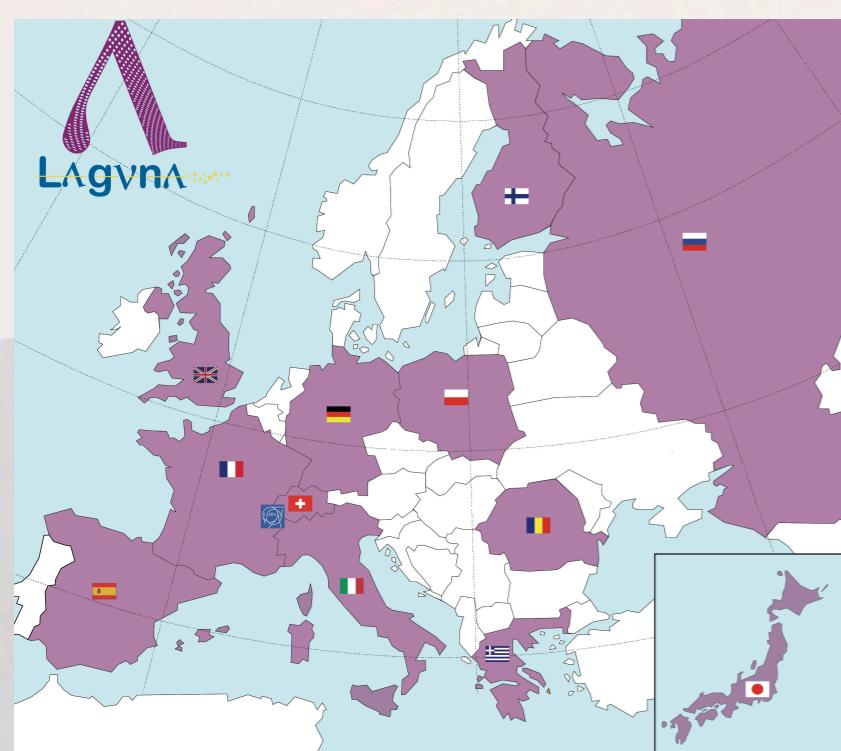




The LAGUNA-LBNO Project

**M. Buizza Avanzini for the LAGUNA-LBNO Collaboration
APC Laboratory, Paris**

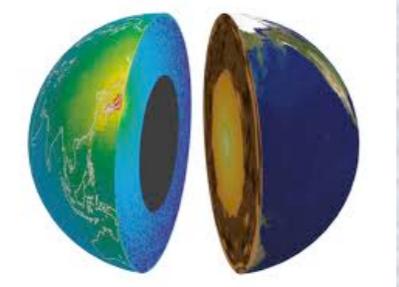
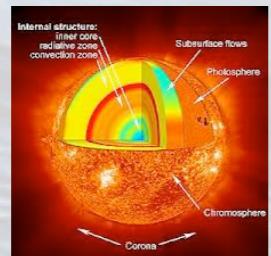
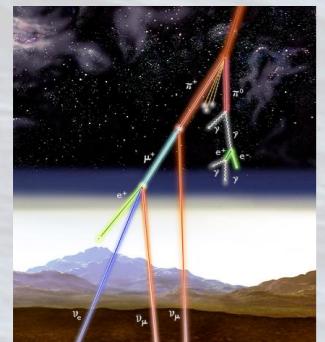
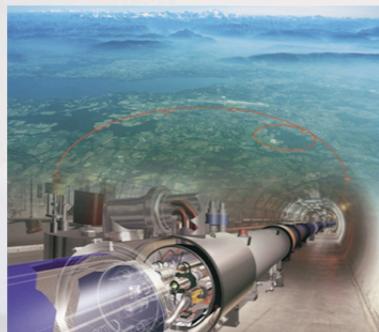
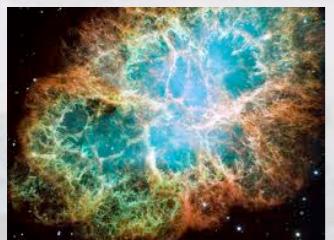


LAGUNA-LBNO: Large Apparatus for Grand Unification and Neutrino Astrophysics and Long Baseline Neutrino Oscillations

LAGUNA-LBNO consortium = 13 countries, 45 institutions, ~300 members

FP7 DS: 2011 - 2014; 4.9 M€

LAGUNA-LBNO Physics:



1. Accelerator based:

- Mass Hierarchy
- δ_{CP}
- PMNS precision
- 3 ν or 3+n ?

large θ_{13}

2. Non-Accelerator based:

- Proton decay

3. Neutrino Astronomy:

- Supernova neutrinos
- Diffuse Supernova Neutrinos
- Solar Neutrinos
- Atmospheric Neutrinos

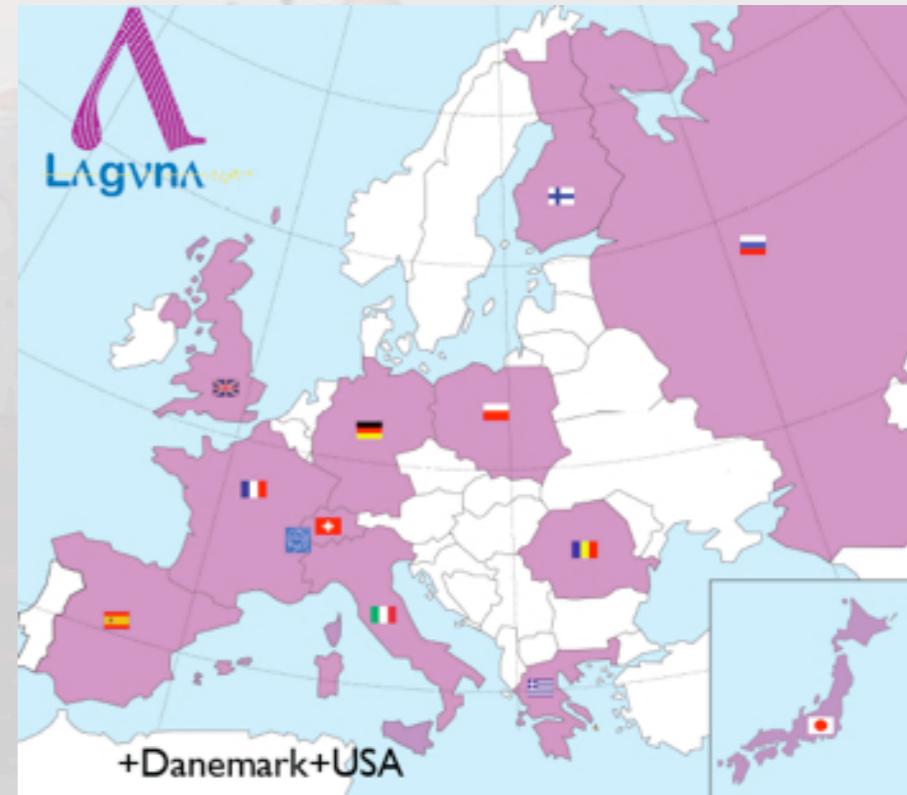
4. Geo neutrinos

5. Dark Matter

LAGUNA-LBNO consortium

Large Apparatus for Grand Unification and Neutrino Astrophysics
and
Long Baseline Neutrino Oscillations

- **LAGUNA DS** (FP7 Design Study 2008-2011)
 - ~ 100 members; 10 countries
 - 3 detector technologies \otimes 7 sites, different baselines ($130 \rightarrow 2300\text{km}$)
- **LAGUNA-LBNO DS** (FP7 DS Long Baseline Neutrino Oscillations, 2011-2014)
 - ~300 members; 14 countries + CERN
 - Down selection of sites & detectors
- **LBNO** (CERN SPSC EoI for a very long baseline neutrino oscillation experiment, June 2012)
 - An incremental approach, based on the findings of LAGUNA
 - ~230 authors; 51 institutions
 - CERN-SPSC-2012-021 ; SPSC-EOI-007, under review



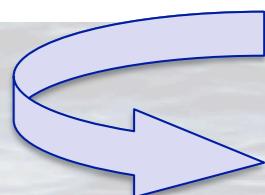
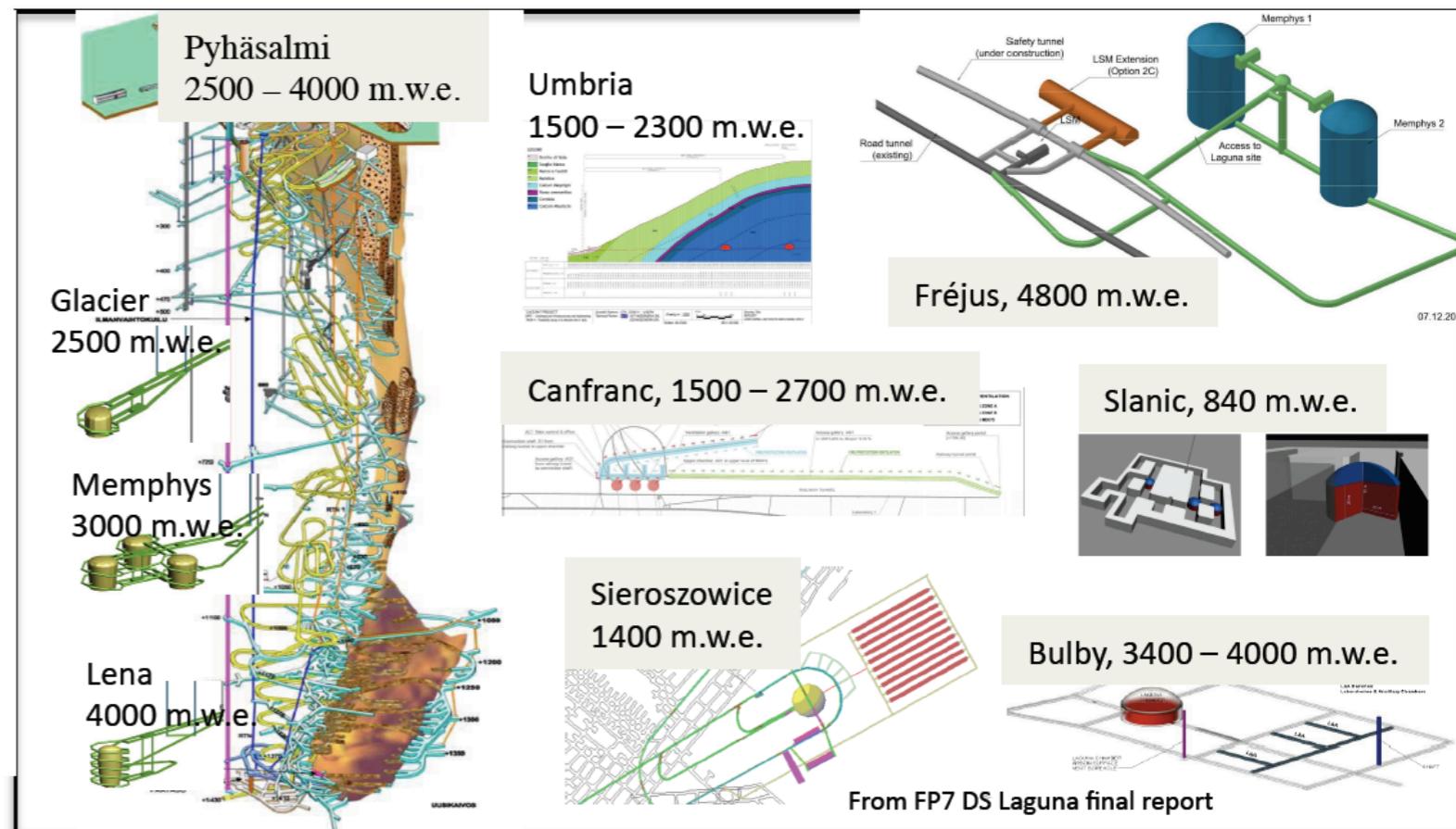
Steering group:

Alain Blondel (UniGe),
Ilias Efthymiopoulos (CERN)
Takuya Hasegawa (KEK)
Yuri Kudenko (INR)
Guido Nuijten (Rockplan, Helsinki)
Lothar Oberauer (TUM)
Thomas Patzak (APC, Paris)
Silvia Pascoli (Durham)
Federico Petrolo (ETH Zürich)
André Rubbia (ETH Zürich)
Chris Thompson (Alan Auld Engineering)
Wladyslaw Trzaska (Jyväskylä)
Alfons Weber (Oxford)
Marco Zito (CEA)

LAGUNA (2008 - 2011):

~ 100 members; EU funding 1,7 M€

- ✓ LAGUNA => very comprehensive evaluation of all sites, construction and costs
- ✓ LAGUNA => baselines from 130 km to 2300 km available in Europe = advantage
- ✓ LAGUNA => allowed to form a strong community in Europe (> 100 physicists and Ing.)
- ✓ LAGUNA => showed the need to evaluate constraints and costs for the detector options

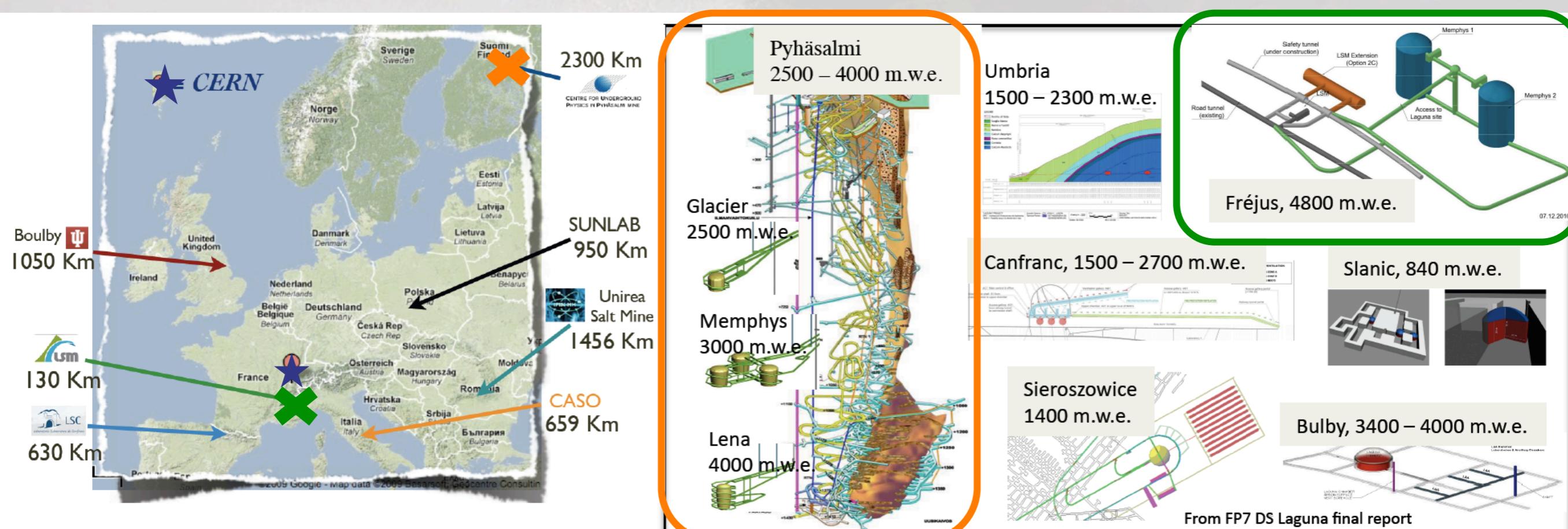


New program: LAGUNA-LBNO, Start September 2011 – End September 2014

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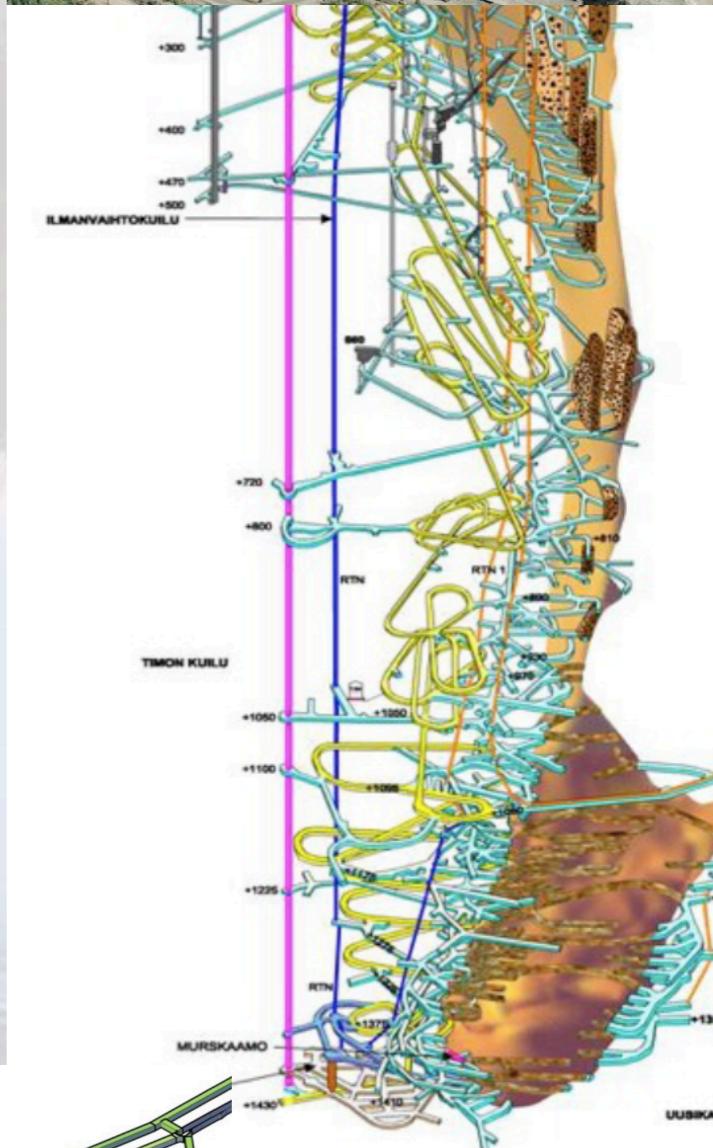
LAGUNA-LBNO (2011 - 2014)

EOI for a very long baseline neutrino oscillation experiment

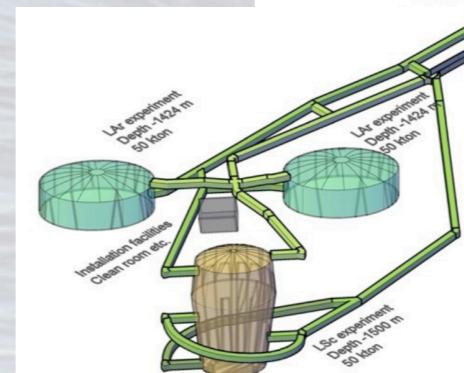
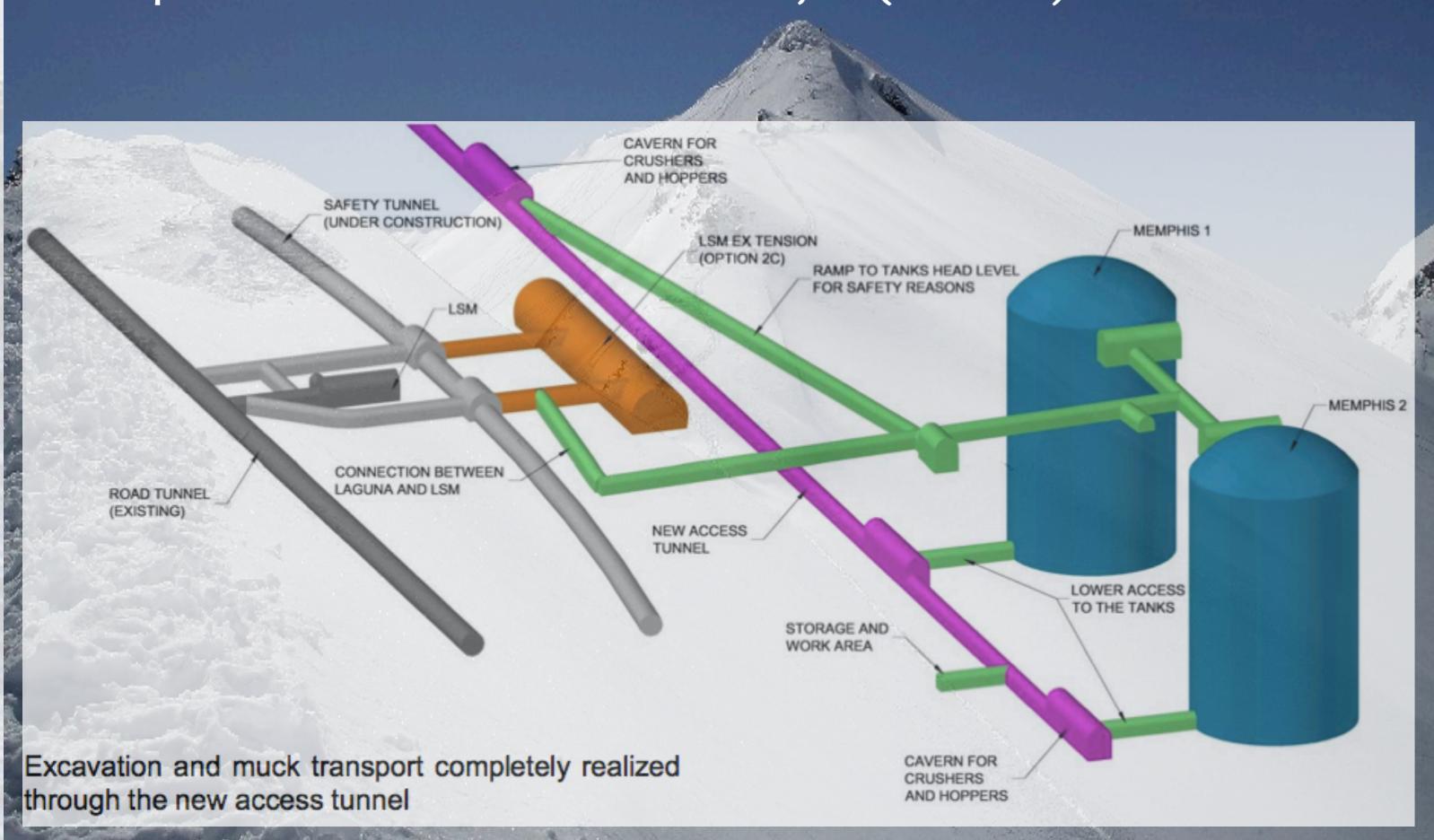
CERN-SPSC-2012-021; SPSC-EOI-007

1. Longest baseline (2300 km), CERN -> Pyhäsalmi: matter effect; mass hierarchy, LCPV
2. Shortest baseline (130 km), CERN -> Fréjus: no matter effects; clean measurement of LCPV

1st option: LAGUNA-LBNO at Pyhäsalmi (Finland)

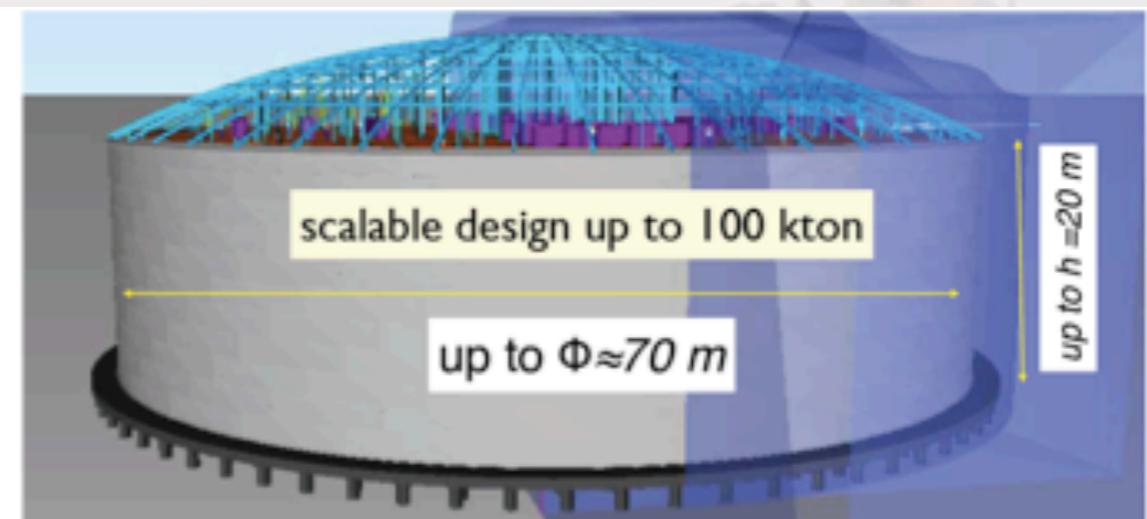
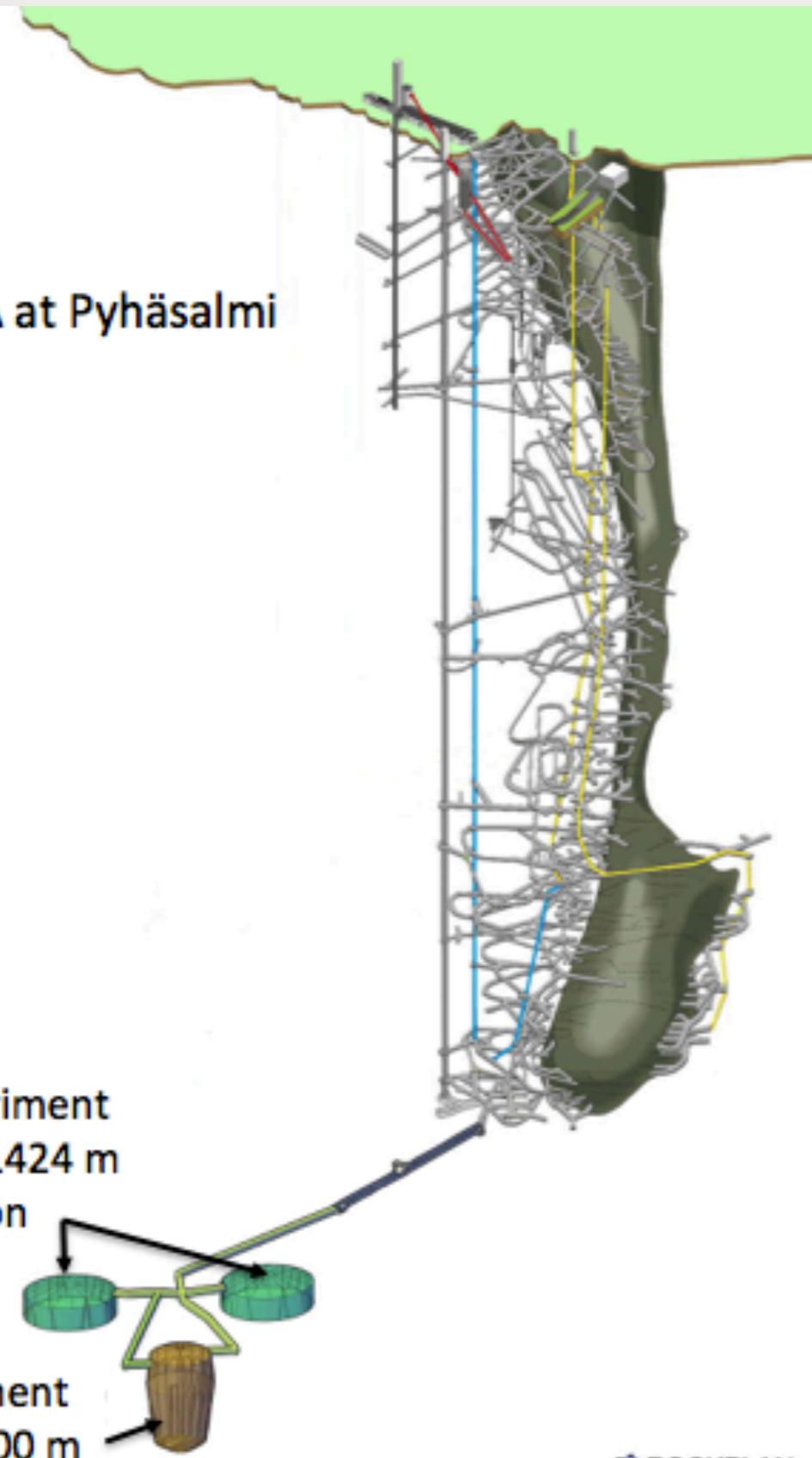


2nd option: LAGUNA-LBNO at Fréjus (France)

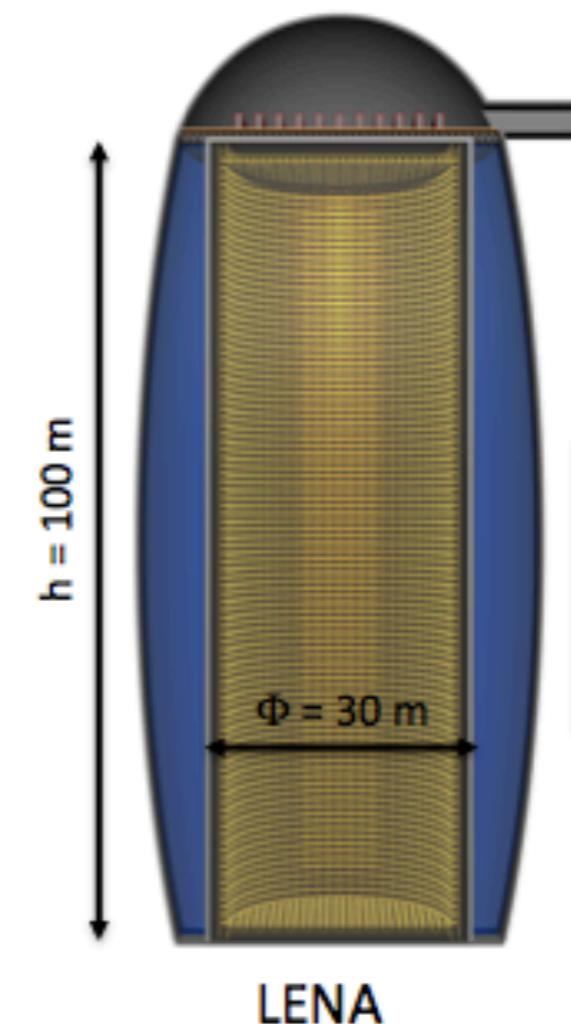


LAGUNA-LBNO Detectors: Desiderata

LAGUNA at Pyhäsalmi
Finland



GLACIER



LENA

talk by
S.
Murphy,
Id [33]

talks by
M. Wurm , id [41]
K. Loo, id [153]

LBNO EOI: Physics Program

LBNO EOI: main goals are MH determinaiton and δ_{CP} discovery

To measure MH on the $> 5\sigma$ level one need to go to very long baselines, ~ 1000 km gives not enough MSW effect to be independent of δ_{CP}

Global fits of many experiments can guide and help the research but cannot replace the measurement of a dedicated experiment.

LBNO aims at exploring and resolve the mass hierarchy and the CP-phase problem by observing clear signatures and determining their L/E dependence → Very Long Baseline

LAGUNA-LBNO Strategy

► Incremental approach:

- **1st stage:** ➤ «conventional» beam based on 400 GeV protons from the SPS
700 kW
➤ total 1.5×10^{21} PoT (**10 - 12 years**)
➤ **20 kt LAr detector and 35 kt iron/scintillator detector**
- **2nd stage:** upgrade detector to **70 kt** and / or the beam power to **2 MW**

► L/E behavior: measurement of the energy dependence of the oscillation probabilities ranging from the 1st to the 2nd maximum

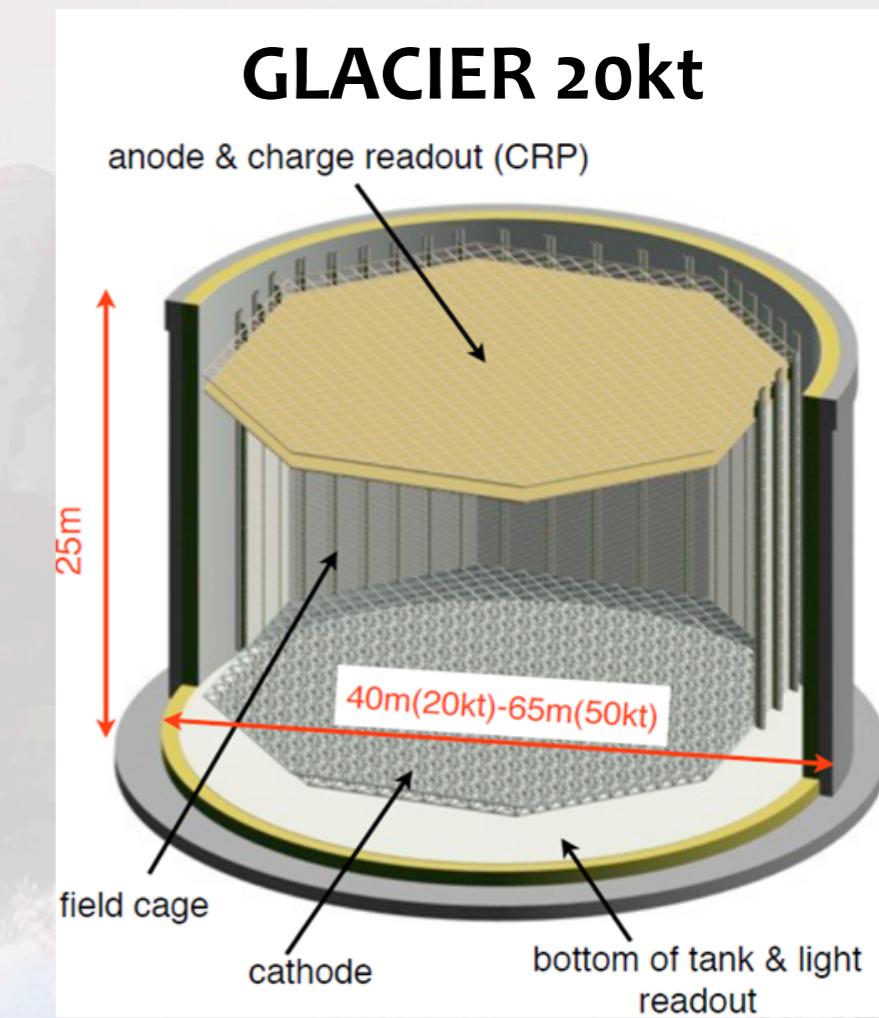
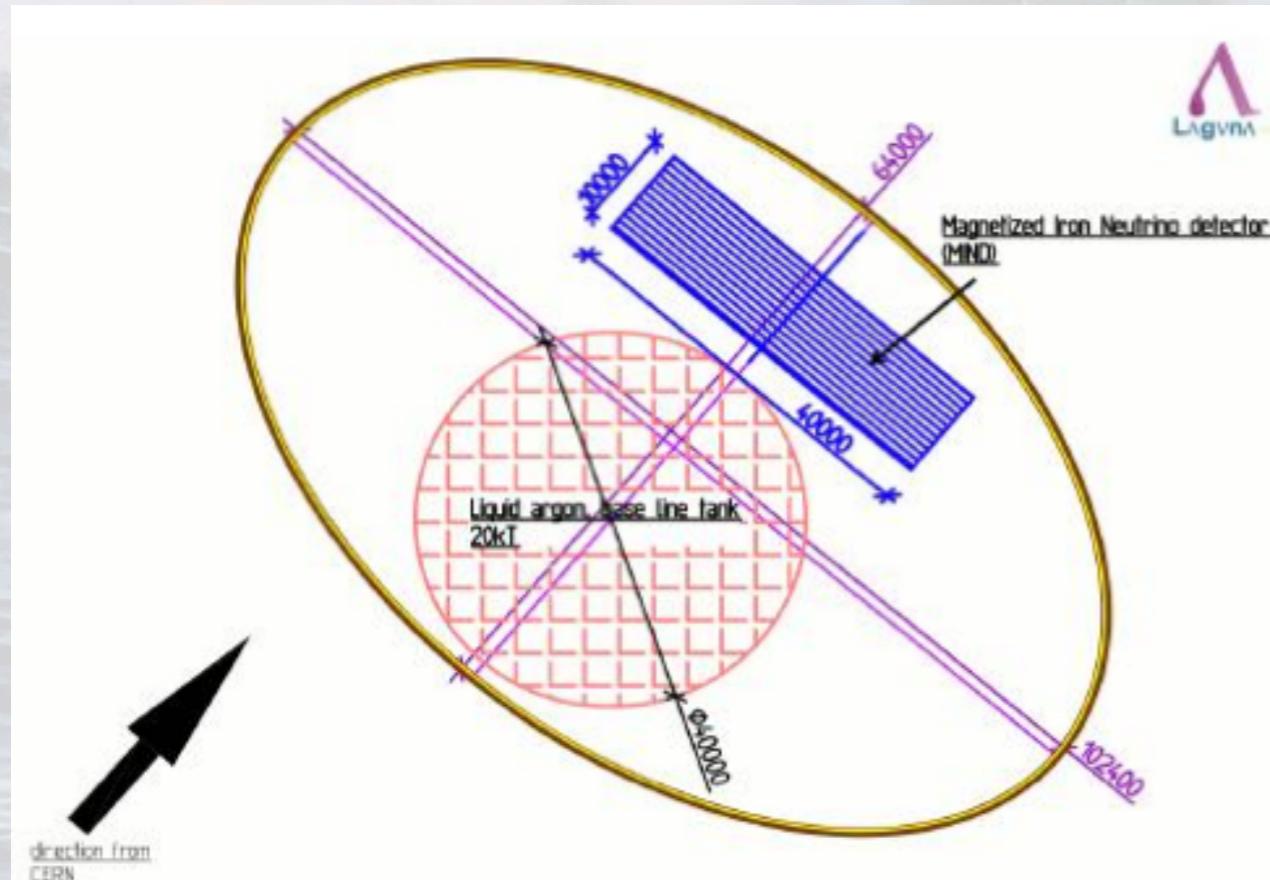
► Measure all transitions:

- Appearance: $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu \rightarrow \nu_\tau$
- Disappearance: $\nu_\mu \rightarrow \nu_\mu$
- neutral currents

Far Detectors

Requirements:

- Fiducial mass of at least **20kt** in first phase (c.f. SuperK 22.5kt)
- Fine granularity reconstruction for **electron neutrino appearance**
- Efficient over a broad energy range $0.5\text{GeV} < E < 10\text{GeV}$ with $\sigma_E/E \sim 10\%$ to observe **L/E spectrum**



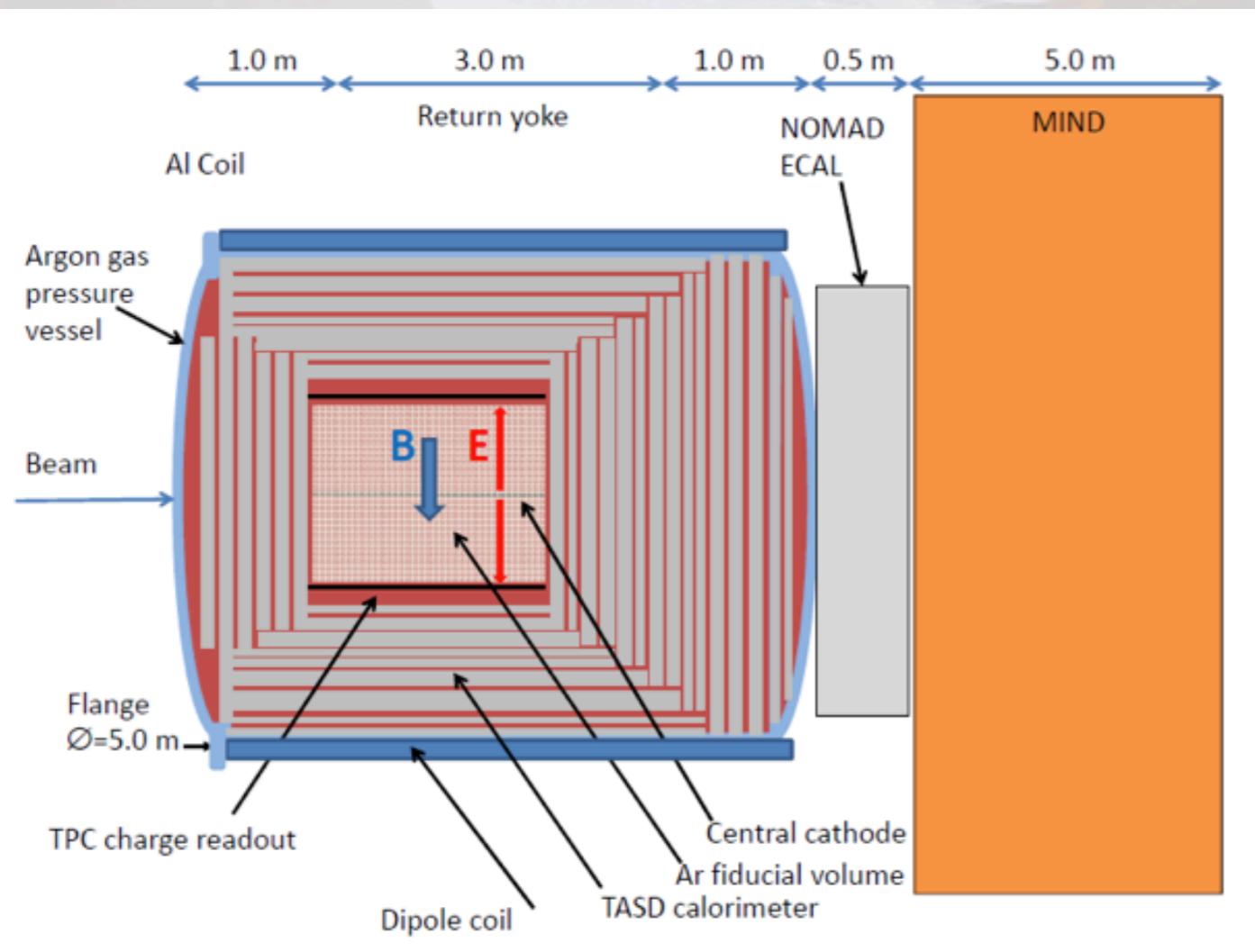
Reference Design:

- 20 kt Double phase Liquid argon TPC (**GLACIER**)
- + 35 kt magnetised iron detector (**MIND**)

See talk by S. Murphy later

Near detector

Aim: systematic errors for signal and backgrounds in the far detectors below $\pm 5\%$, possibly at the level of $\pm 2\%$
⇒ control of fluxes, cross-sections, efficiencies,...



- Concept: 20 bar gas argon-mixture TPC ($2.4 \text{ m} \times 2.4 \text{ m} \times 3 \text{ m}$) surrounded by scintillator bar tracker embedded in an instrumented magnet with field 0.5 T
- 600 kg argon mass in TPC
- 0.2 event/spill @ $7e^{13} \text{ ppp}$ 400 GeV
- O(100'000) events/year
- + MIND detector

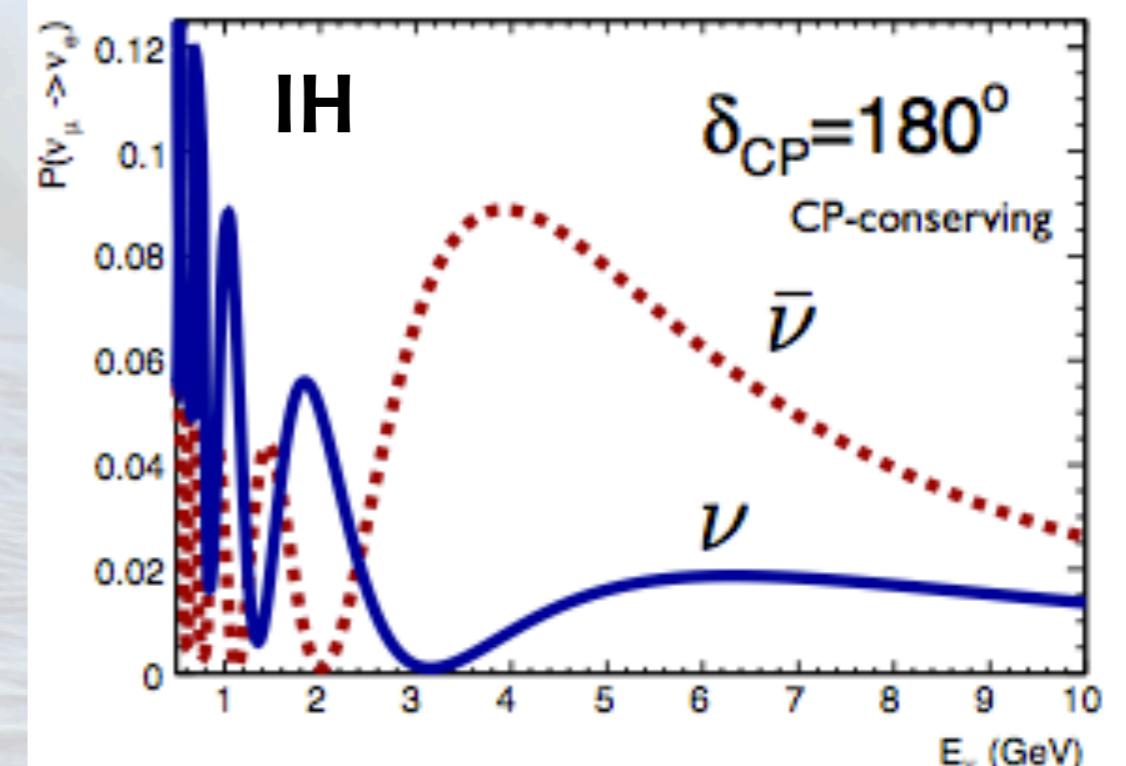
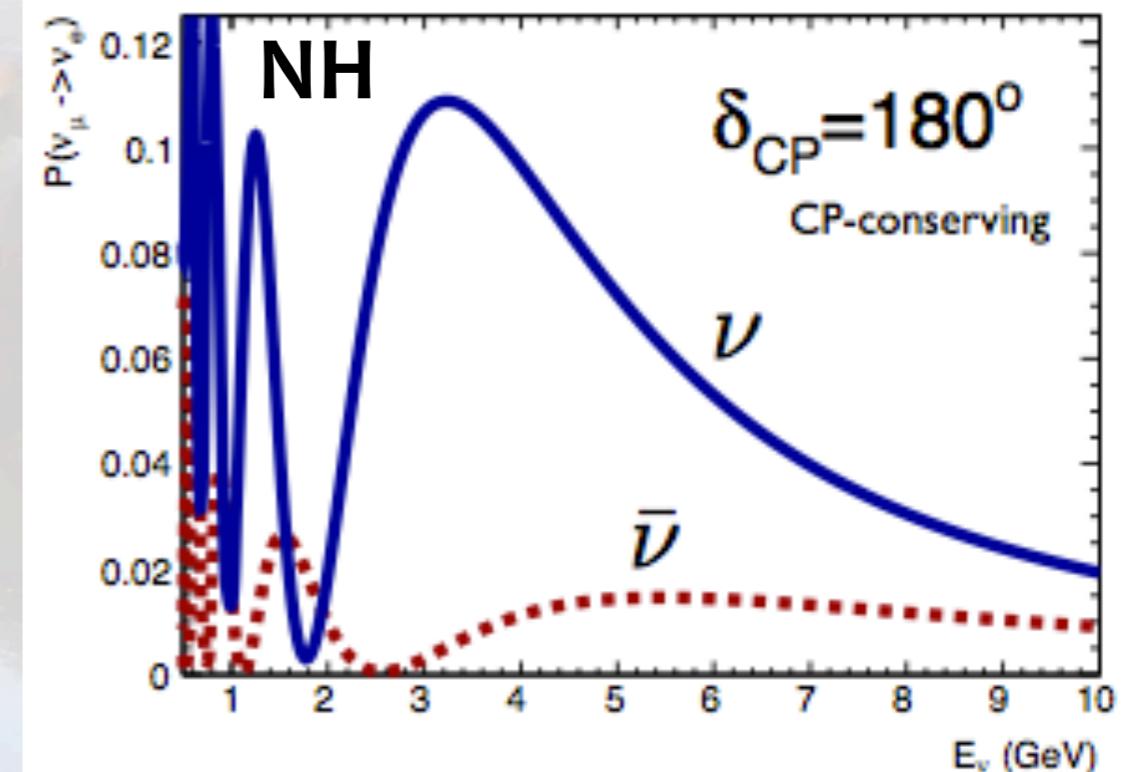
Reaching very long baselines

L=2300 km

- ★ “Zoom effect”: The L/E dependence can be observed in an “expanded” scale at large L

⇒ Measure the full spectral information for unambiguous sensitivity and a direct proof of the observed phenomenon.

- ★ Decoupling of MH and CPV: A guaranteed & conclusive sensitivity to MH with existing beam power and initial mass requires a very long baseline.
⇒ After MH fixed, optimise the running for CP (this depends on NH/IH)!

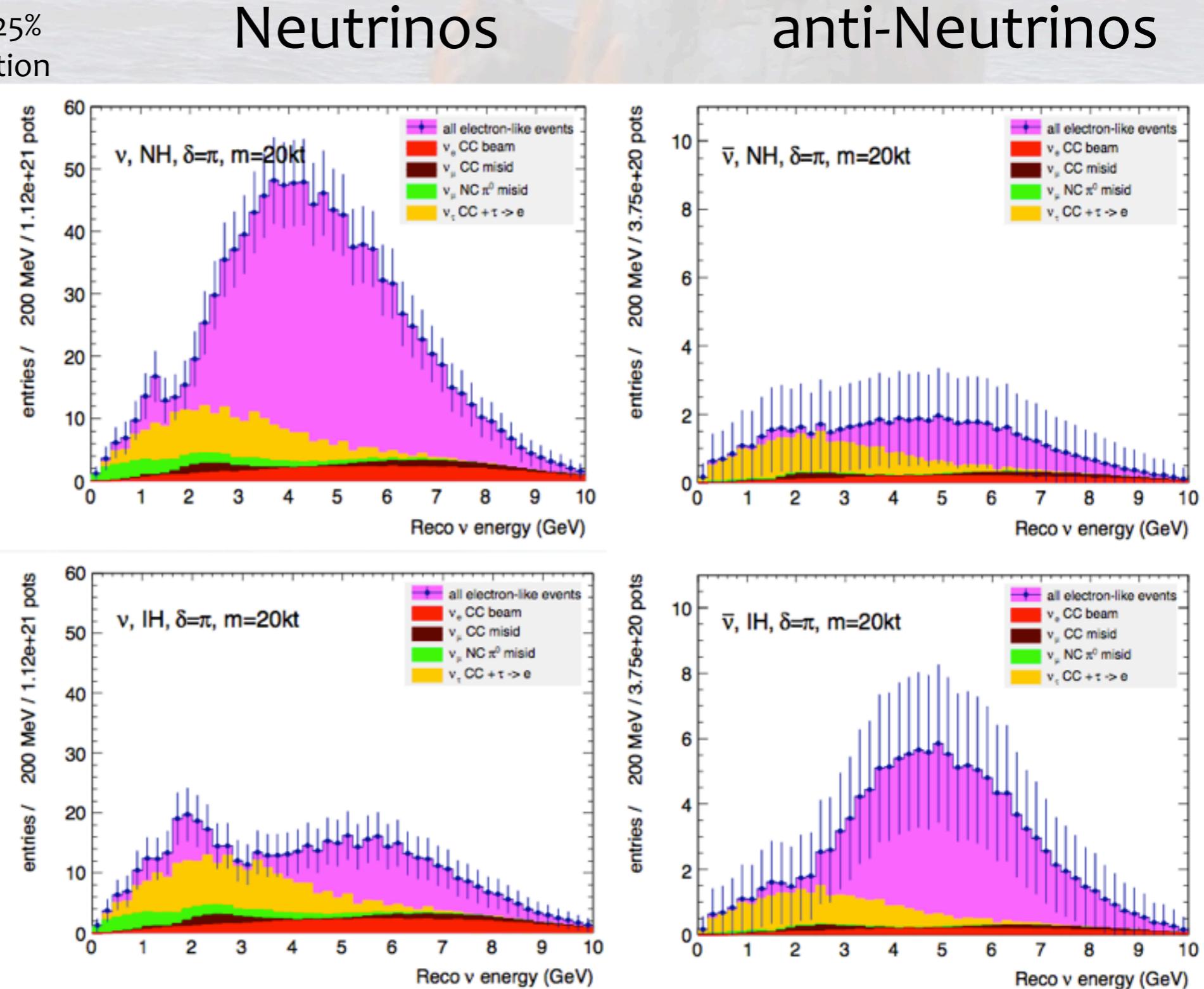


LBNO 1st phase: Mass Hierarchy

$\nu + \text{anti-}\nu$ running to distinguish NH from IH

- 20 kt fid. mass LAr
- Running mode: $\nu/\text{anti-}\nu$: 75% / 25%
- Detector response and resolution included
- 1.5×10^{21} pot

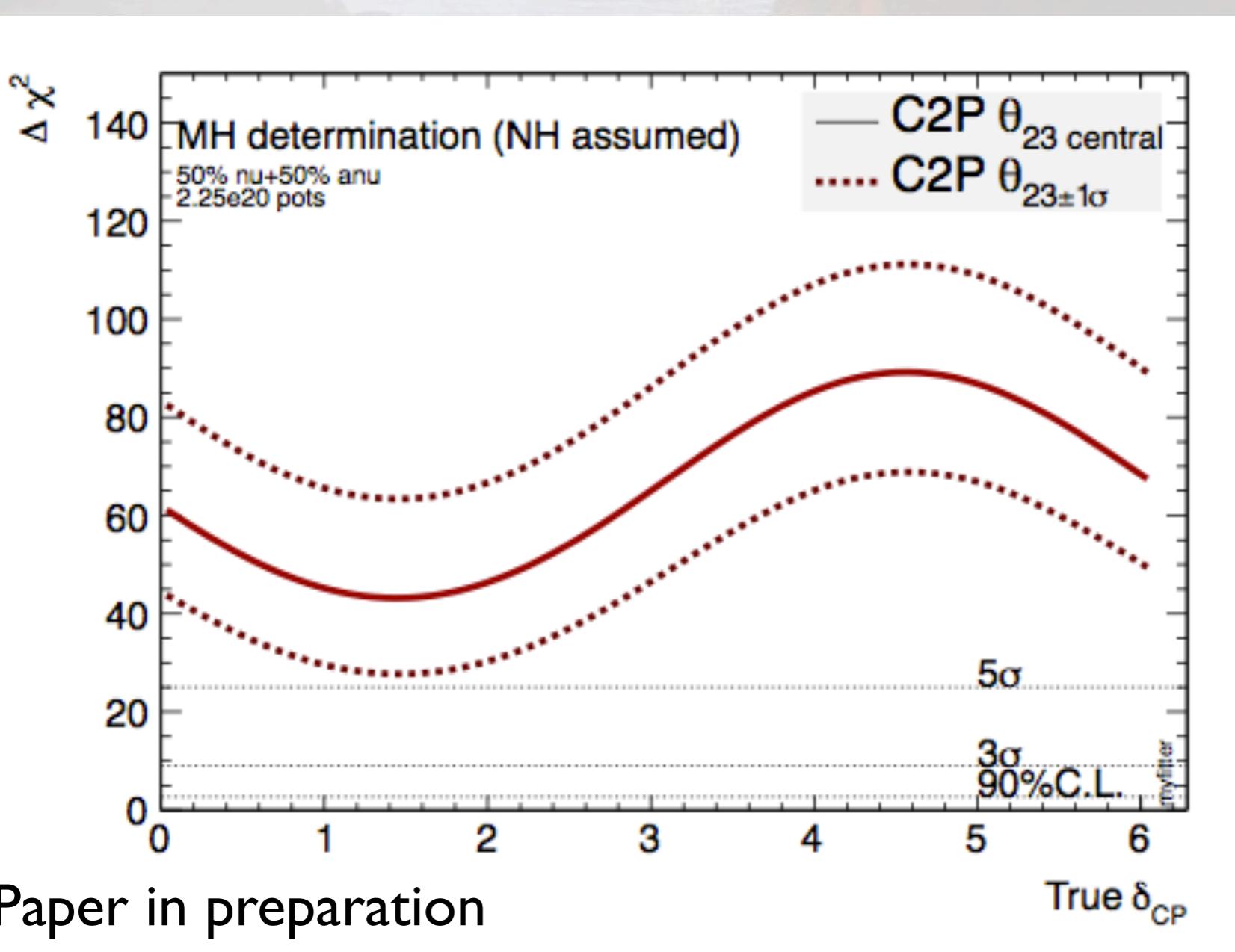
NH



LBNO 1st phase: Mass Hierarchy Sensitivity

LBNO will provide a

- $> 5\sigma$ direct determination of MH
- independent of the values of θ_{23} & δ_{CP}
 - in ≈ 2 years of running



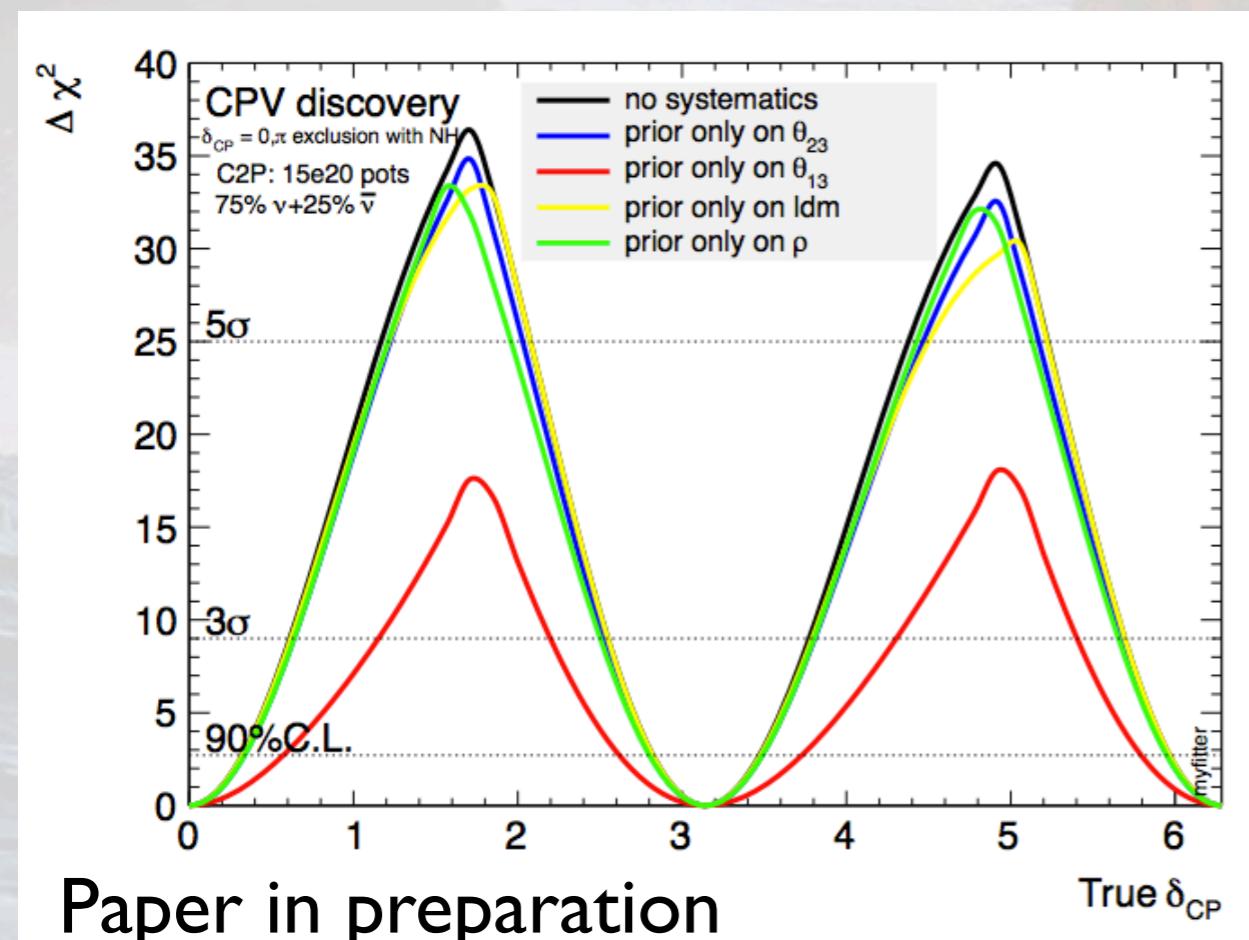
Extracting MH from global fits can not replace a direct 5σ measurement from an experiment!

LBNO 1st phase: δ_{CP} Sensitivity

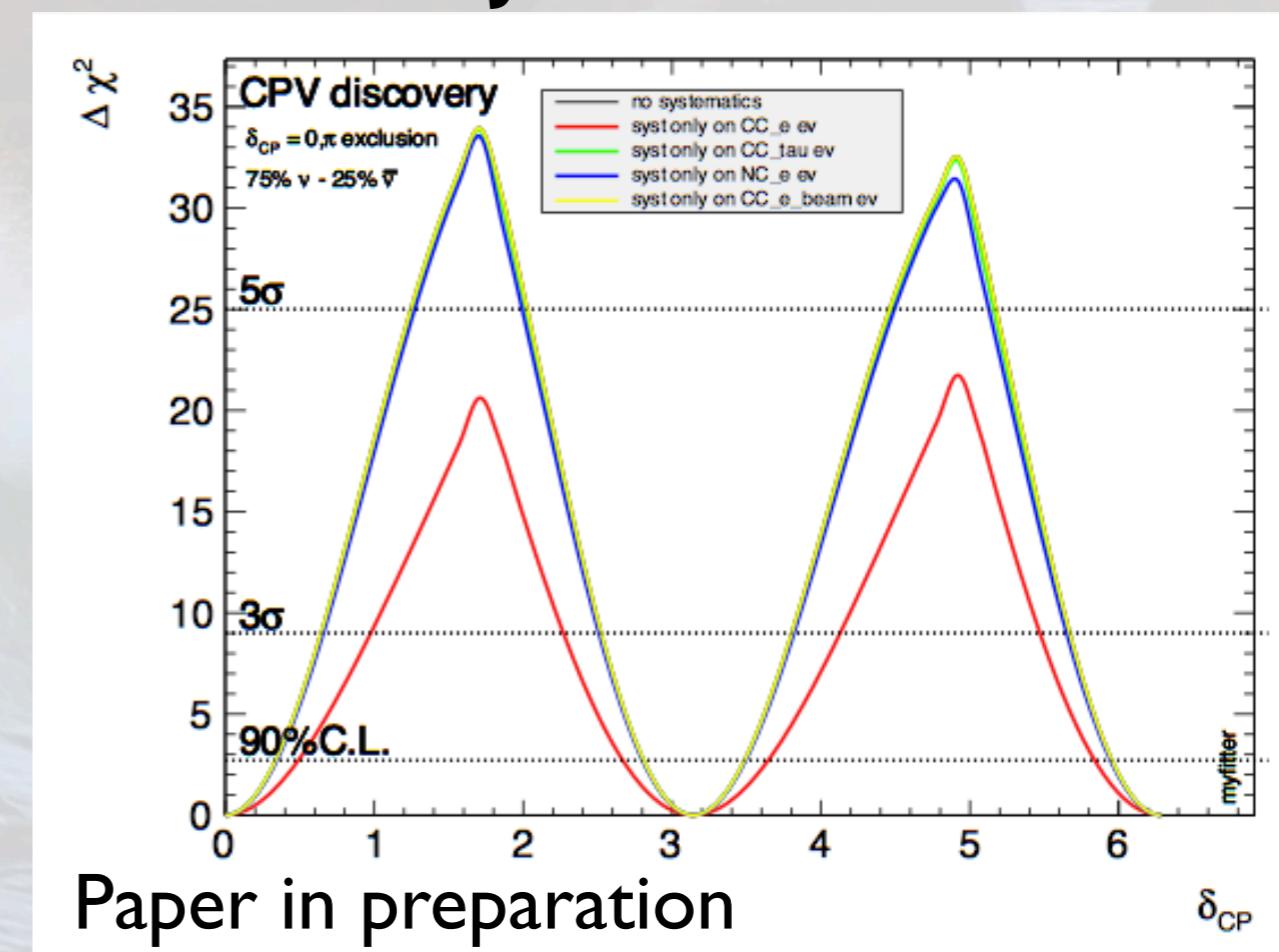
Once MH determined: run for 8 to 10 years with optimized sharing of neutrinos / anti-neutrinos to **cover the most possible phase space in δ_{CP}**

Use best knowledge on systematics and oscillation parameters

Oscillation parameters



Paper in preparation

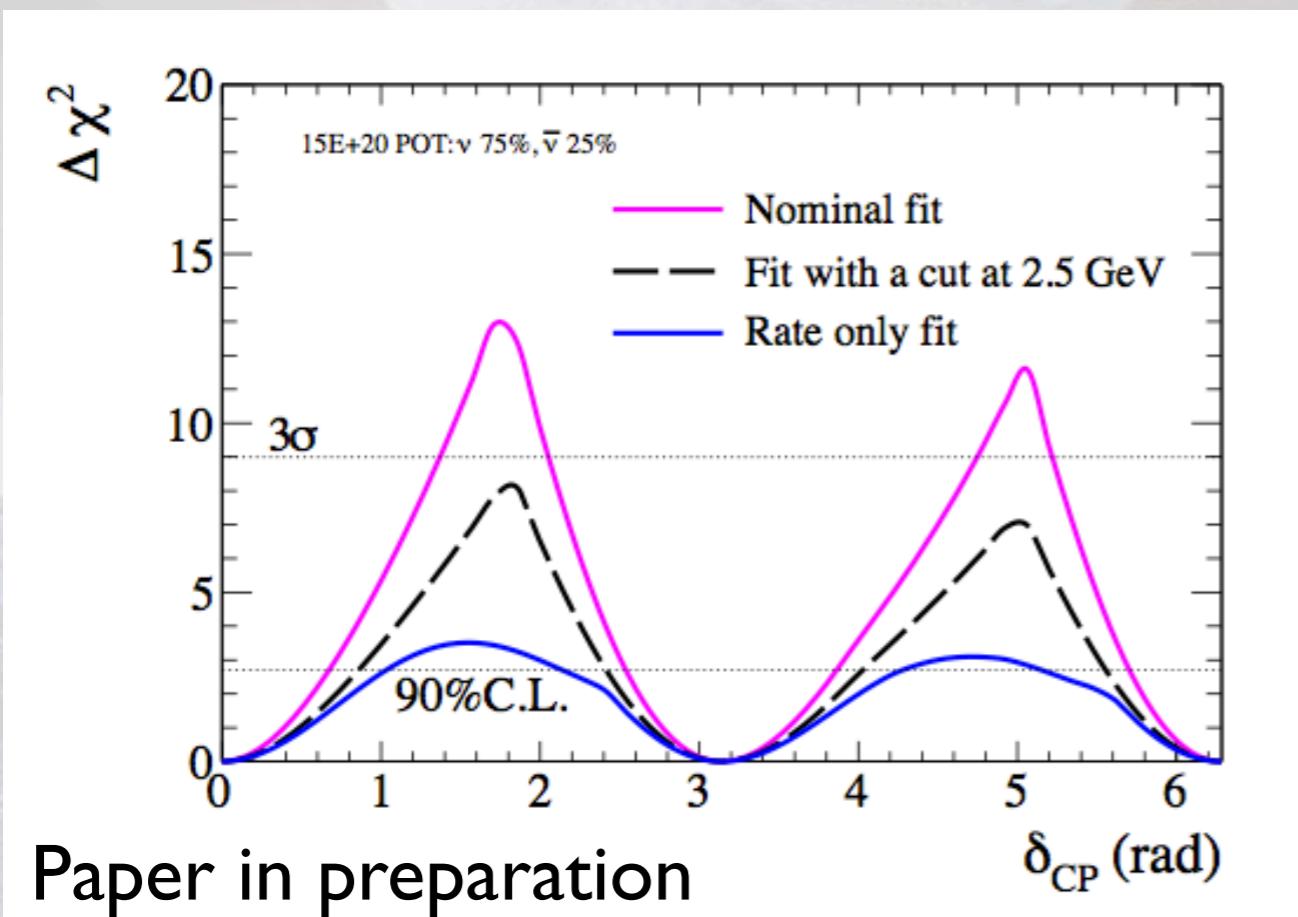


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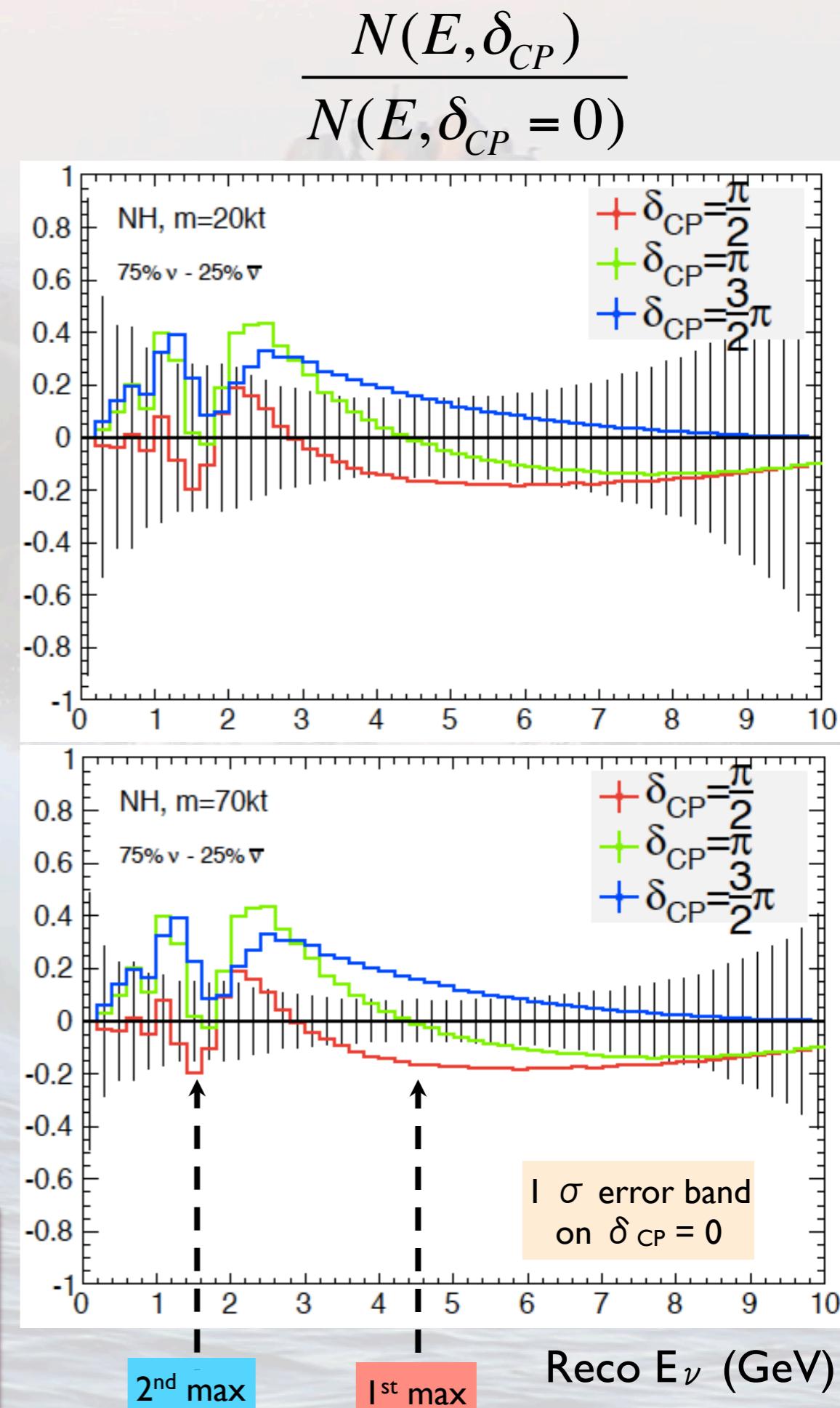
- The most important oscillation parameter is θ_{13}
- the most important systematics is the knowledge of the absolute rate of ν_e CC events

δ_{CP} Sensitivity: why study 1st and 2nd maxima?

Use all spectral information:
Rate & Shape for energy range 1st - 2nd max



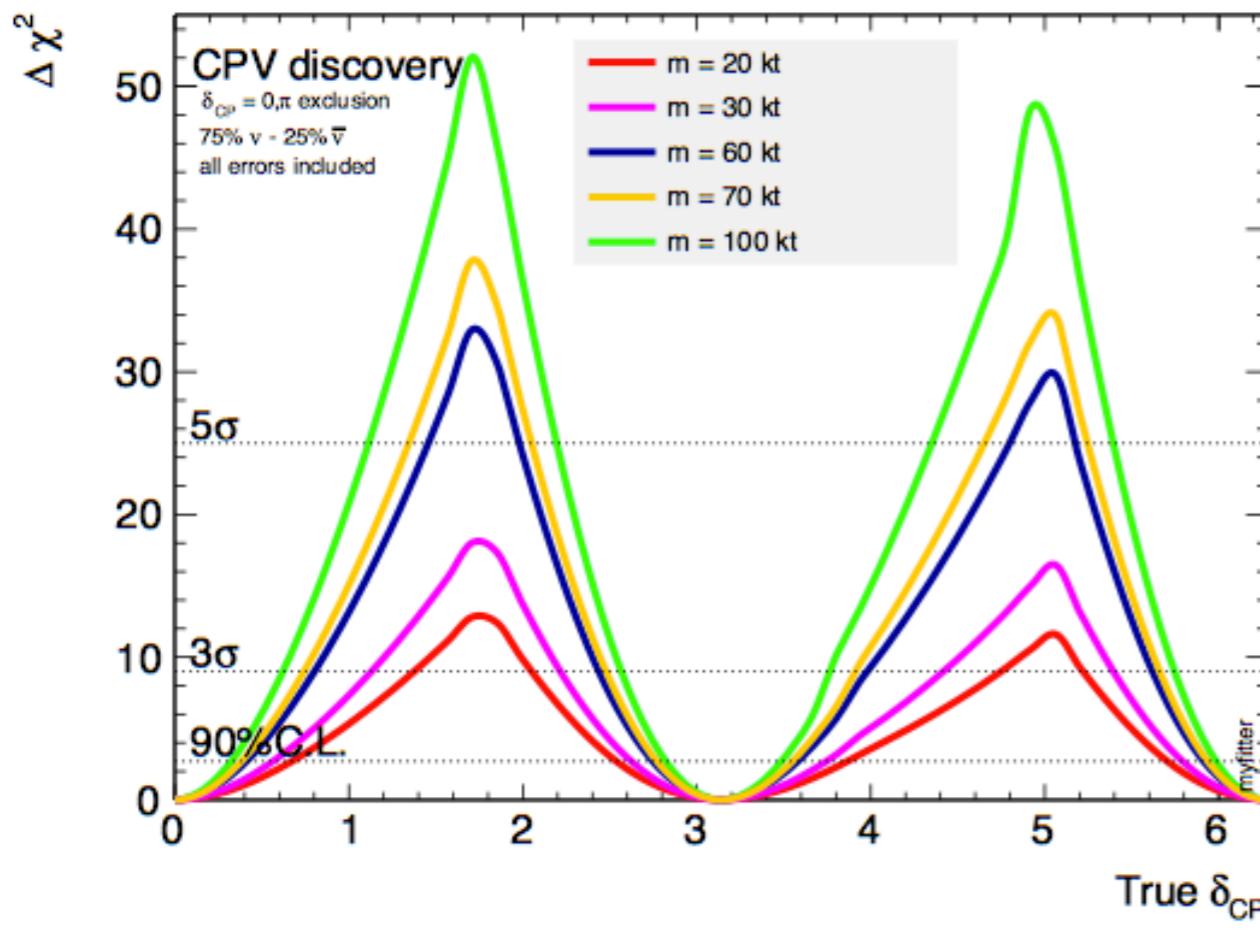
The 1st maximum,
although statistically, is
rather featureless



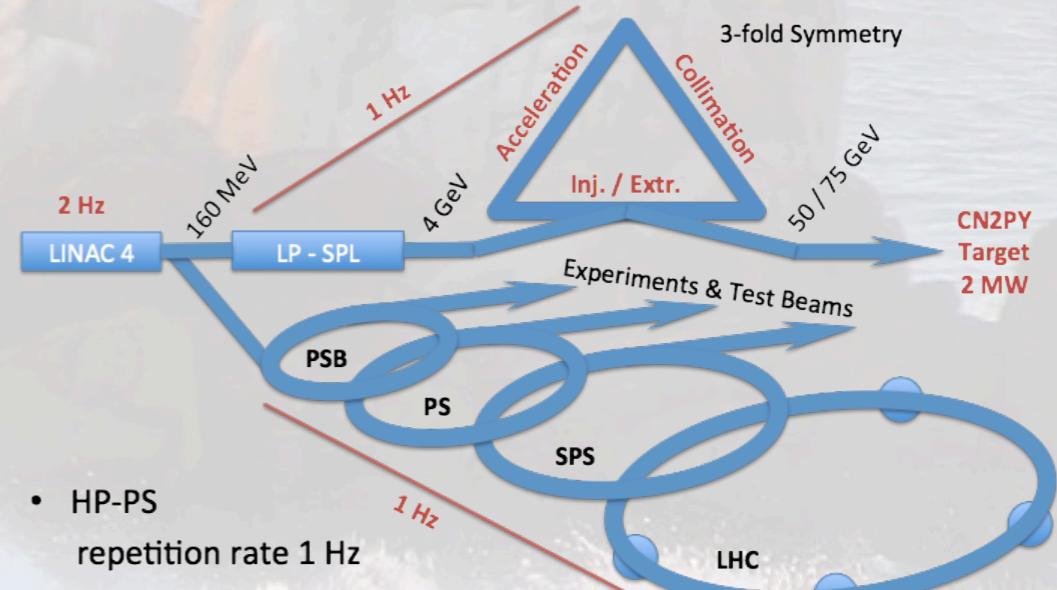
LBNO 2nd phase: δ_{CP} Discovery

Go to stage II to measure 5σ CPV:
Increase mass and/or beam power

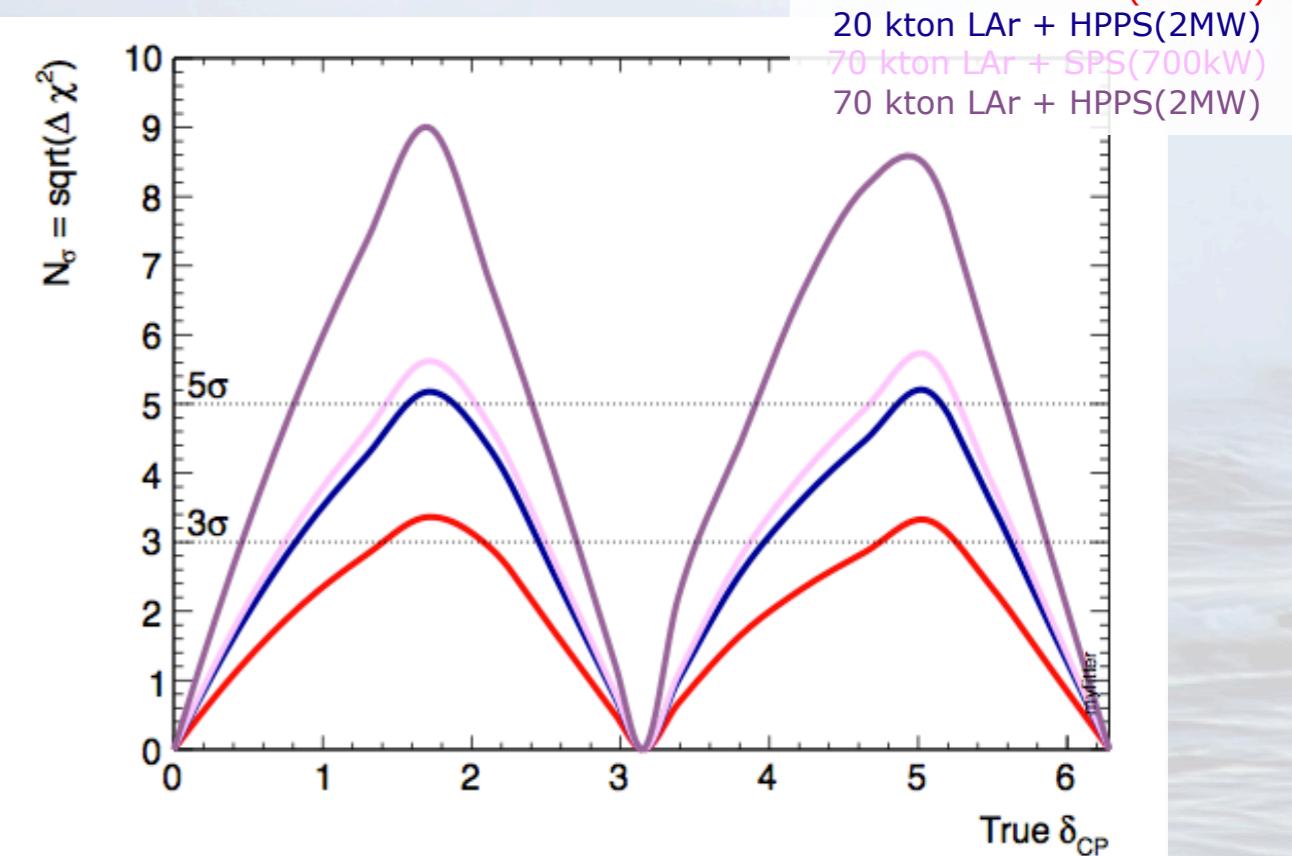
1.5×10^{21} p.o.t.



High power HP-PS study



- HP-PS
repetition rate 1 Hz



Conclusions

- LAGUNA/LBNO is a project with a very rich and interesting physics program with **fundamental discovery potential**.
- The LAGUNA-LBNO collaboration decided to propose **stage I** of 20kt LAr + 700 kW SPS at 2300km of baseline
- Outstanding Physics Potential:
 - 1. Accelerator Neutrino based (LBNO):
 - Mass Hierarchy $> 5 \sigma$ all phase space in 2y
 - δ_{CP}
 - PMNS precision $\rightarrow 3 \nu$ or $3+n$?
 - 2. Non-Accelerator based:
 - Proton decay: Significantly extended sensitivity to nucleon decay in many channels.
 $Br(p \rightarrow \text{anti-}\nu \ K) > 2 \times 10^{34} \text{y}$ (90% C.L.)
 $Br(n \rightarrow e^- K^+) > 2 \times 10^{34} \text{y}$ (90% C.L.)
 - 3. Neutrino Astronomy:
 - Supernova neutrinos > 10000 's events @ SN explosion @ 10kpc
 - Diffuse Supernova Neutrinos (DSN)
 - Neutrinos from DM annihilation
 - Atmospheric Neutrinos (5600 events/y)

Milestones - Timescale

LAGUNA Design Study funded for site studies:	2008-2011
Categorize the sites and down-select:	Sept. 2010
Start of LAGUNA-LBNO	2011
Submission of LBNO EoI to CERN	2012
End of LAGUNA-LBNO DS: technical designs, layouts, liquids handling&storage, safety, ...	2014
Critical decision	2015 ?
Excavation-construction (incremental):	2016-2021 ?
Phase 1 LBL physics start:	2023 ?
Phase 2 incremental step implementation:	>2025 ?

Towards a real experiment: SPSC-EoI-007: «Expression of Interest for a very long baseline neutrino oscillation experiment (LBNO)»

A. Stahl,¹ C. Wiebusch,¹ A. M. Guler,² M. Kamiscioglu,² R. Sever,² A.U. Yilmazer,³ C. Gunes,³ D. Yilmaz,³ P. Del Amo Sanchez,⁴ D. Duchesneau,⁴ H. Pessard,⁴ E. Marcoulaki,⁵ I. A. Papazoglou,⁵ V. Berardi,⁶ F. Cafagna,⁶ M.G. Catanesi,⁶ L. Magaletti,⁶ A. Mercadante,⁶ M. Quinto,⁶ E. Radicioni,⁶ A. Ereditato,⁷ I. Kreslo,⁷ C. Pistillo,⁷ M. Weber,⁷ A. Ariga,⁷ T. Ariga,⁷ T. Strauss,⁷ M. Hierholzer,⁷ J. Kawada,⁷ C. Hsu,⁷ S. Haug,⁷ A. Jipa,⁸ I. Lazanu,⁸ A. Cardini,⁹ A. Lai,⁹ R. Oldeman,¹⁰ M. Thomson,¹¹ A. Blake,¹¹ M. Prest,¹² A. Auld,¹³ J. Elliot,¹³ J. Lombard,¹³ C. Thompson,¹³ Y.A. Gornushkin,¹⁴ S. Pascoli,¹⁵ R. Collins,¹⁶ M. Haworth,¹⁶ J. Thompson,¹⁶ G. Bencivenni,¹⁷ D. Domenici,¹⁷ A. Longhin,¹⁷ A. Blondel,¹⁸ A. Bravar,¹⁸ F. Dufour,¹⁸ Y. Karadzhov,¹⁸ A. Korzenev,¹⁸ E. Noah,¹⁸ M. Ravonel,¹⁸ M. Rayner,¹⁸ R. Asfandiyarov,¹⁸ A. Haesler,¹⁸ C. Martin,¹⁸ E. Scantamburlo,¹⁸ F. Cadoux,¹⁸ R. Bayes,¹⁹ F.J.P. Soler,¹⁹ L. Aalto-Setälä,²⁰ K. Enqvist,²⁰ K. Huitu,²⁰ K. Rummukainen,²⁰ G. Nuijten,²¹ K.J. Eskola,²² K. Kainulainen,²² T. Kalliokoski,²² J. Kumpulainen,²² K. Loo,²² J. Maalampi,²² M. Manninen,²² I. Moore,²² J. Suhonen,²² W.H. Trzaska,²² K. Tuominen,²² A. Virtanen,²² I. Bertram,²³ A. Finch,²³ N. Grant,²³ L.L. Kormos,²³ P. Ratoff,²³ G. Christodoulou,²⁴ J. Coleman,²⁴ C. Touramanis,²⁴ K. Mavrokoridis,²⁴ M. Murdoch,²⁴ N. McCauley,²⁴ D. Payne,²⁴ P. Jonsson,²⁵ A. Kaboth,²⁵ K. Long,²⁵ M. Malek,²⁵ M. Scott,²⁵ Y. Uchida,²⁵ M.O. Wascko,²⁵ F. Di Lodovico,²⁶ J.R. Wilson,²⁶ B. Still,²⁶ R. Sacco,²⁶ R. Terri,²⁶ M. Campanelli,²⁷ R. Nichol,²⁷ J. Thomas,²⁷ A. Izmaylov,²⁸ M. Khabibullin,²⁸ A. Khotjantsev,²⁸ Y. Kudenko,²⁸ V. Matveev,²⁸ O. Mineev,²⁸ N. Yershov,²⁸ V. Palladino,²⁹ J. Evans,³⁰ S. Söldner-Rembold,³⁰ U.K. Yang,³⁰ M. Bonesini,³¹ T. Pihlajaniemi,³² M. Weckström,³² K. Mursula,³² T. Enqvist,³² P. Kuusiniemi,³² T. Rähä,³² J. Sarkamo,³² M. Slupecki,³² J. Hissa,³² E. Kokko,³² M. Aittola,³² G. Barr,³³ M.D. Haigh,³³ J. de Jong,³³ H. O'Keeffe,³³ A. Vacheret,³³ A. Weber,^{33,34} G. Galvanin,³⁵ M. Temussi,³⁵ O. Caretta,³⁴ T. Davenne,³⁴ C. Densham,³⁴ J. Illic,³⁴ P. Loveridge,³⁴ J. Odell,³⁴ D. Wark,³⁴ A. Robert,³⁶ B. Andrieu,³⁶ B. Popov,^{36,14} C. Giganti,³⁶ J.-M. Levy,³⁶ J. Dumarchez,³⁶ M. Buizza-Avanzini,³⁷ A. Cabrera,³⁷ J. Dawson,³⁷ D. Franco,³⁷ D. Kryn,³⁷ M. Obolensky,³⁷ T. Patzak,³⁷ A. Tonazzo,³⁷ F. Vanucci,³⁷ D. Orestano,³⁸ B. Di Micco,³⁸ L. Tortora,³⁹ O. Bésida,⁴⁰ A. Delbart,⁴⁰ S. Emery,⁴⁰ V. Galymov,⁴⁰ E. Mazzucato,⁴⁰ G. Vasseur,⁴⁰ M. Zito,⁴⁰ V.A. Kudryavtsev,⁴¹ L.F. Thompson,⁴¹ R. Tsenov,⁴² D. Kolev,⁴² I. Rusinov,⁴² M. Bogomilov,⁴² G. Vankova,⁴² R. Matev,⁴² A. Vorobyev,⁴³ Yu. Novikov,⁴³ S. Kosyanenko,⁴³ V. Suvorov,⁴³ G. Gavrilov,⁴³ E. Baussan,⁴⁴ M. Dracos,⁴⁴ C. Jollet,⁴⁴ A. Meregaglia,⁴⁴ E. Vallazza,⁴⁵ S.K. Agarwalla,⁴⁶ T. Li,⁴⁶ D. Autiero,⁴⁷ L. Chaussard,⁴⁷ Y. Déclais,⁴⁷ J. Marteau,⁴⁷ E. Pennacchio,⁴⁷ E. Rondio,⁴⁸ J. Lagoda,⁴⁸ J. Zalipska,⁴⁸ P. Przewlocki,⁴⁸ K. Grzelak,⁴⁹ G. J. Barker,⁵⁰ S. Boyd,⁵⁰ P.F. Harrison,⁵⁰ R.P. Litchfield,⁵⁰ Y. Ramachers,⁵⁰ A. Badertscher,⁵¹ A. Curioni,⁵¹ U. Degunda,⁵¹ L. Epprecht,⁵¹ A. Gendotti,⁵¹ L. Knecht,⁵¹ S. DiLuise,⁵¹ S. Horikawa,⁵¹ D. Lussi,⁵¹ S. Murphy,⁵¹ G. Natterer,⁵¹ F. Petrolo,⁵¹ L. Periale,⁵¹ A. Rubbia,^{51,*} F. Sergiampietri,⁵¹ and T. Viant⁵¹

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